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DO FIRMS TIME THEIR POLLUTION ABATEMENT INVESTMENTS OPTIMALLY?

BY

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Summary

In this paper we develop an equilibrium business-cycle model for an economy with both clean and dirty (polluting) plants. We conclude that the best time to implement cleaner production technologies is during a slowdown of the economy. Due to external effects and market failures the timing of pollution abatement investments is not expected to be optimal in the real world. We test the optimality of the timing of those investments with data for Germany, the Netherlands, and the USA. It appears that for more than 25 per cent of the sectors pollution abatement investments show significant counter-cyclical behaviour, while in 10 per cent of the sectors these investments are pro-cyclical.

Key words: business-cycle model, pollution abatement investments, cleaning production, environmental regulation

1 INTRODUCTION

Governments are often reluctant to attack environmental problems during a recession. In this paper we argue that the best time to clean the environment is when the economy is slowing down. From the fifties until the beginning of the seventies, the conventional wisdom was that during a recession the economy should be stimulated through an increase in government spending. The arguments used then differ from ours. We believe that the government should concentrate the implementation of certain public projects in times of recession, but only those projects which are necessary for long-run growth, such as investments in infrastructure and the environment. Our motivation is not to dampen output fluctuations per se, but rather to concentrate investment activities in times when the opportunity costs of doing so are lowest.

There is some empirical evidence (see e.g. Bean (1990) and Saint Paul (1993)), that in times of recession firms engage in activities that increase long-run growth at the cost of a temporary fall in production. With pollution abatement investments, things are more complicated, since the main reason for firms to undertake such investments is because they are forced to do so by the government. There-

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fore, the government should announce environmental regulation early enough, to allow firms to time their investments optimally.

In this paper we will first formalise the above mentioned notions in a welfare-theoretic framework by developing a dynamic stochastic first-best model for the timing of pollution abatement expenditures. Next, we will test the model with data for Germany, the Netherlands, and the United States. Our theoretical model describes what the world ideally looks like when there is a central planner with full information who maximises a social welfare function. The aim of this formal modelling exercise is to understand how the most important economic mechanisms concerning the timing of pollution abatement expenditures work. In order to be able to elucidate the most important economic mechanisms at work, the model will, necessarily, be highly stylised.

The model distinguishes between clean and dirty (polluting) plants. Consumer-workers derive utility from consumption and leisure, and disutility from pollution. We do take into account that the taste for a clean environment and the utility derived from consumption today need not be the same as in the future. Furthermore, a dirty plant can be transformed into a clean plant, but this has costs in the form of foregone production. Finally, since most economies are growing over time it will be necessary to continuously implement cleaner production techniques to keep the absolute amount of pollution constant. The model captures this feature by letting some clean plants become dirty in each period. The above described approach provides us with a natural way to analyse the relation between current consumption, labour supply, and pollution, and their future values. We find that, even in this simple set-up, a number of important issues concerning the timing of environmental policies can be tackled. The model allows us to study the effects of permanent and transitory demand and technology shocks on pollution abatement expenditures, as well as the effects of changes in knowledge about the urgency of environmental problems on optimal environmental policy.

Even when the government takes account of pollution externalities by internalising them in the prices or by setting emission standards, the optimality result will only carry over to a decentralised market economy when there are no market failures like for example capital rationing. Otherwise, there is a potential role for governments to subsidise pollution abatement policies during a recession. The potential scope for government action, i.e. the importance of possible market failures, can only be assessed from empirical investigation. We have therefore collected data on pollution abatement investments in different sectors for the US, Germany, and the Netherlands. We look for a business-cycle effect in the ratio of abatement investment to total investment. For more than 60 per cent of the country sectors we do not find a cyclical pattern. A possible reason for this might be that the timing of environmental regulation itself is non-optimal. Another reason could be that we have used sectoral data rather than data on the firm level. In only three sectors do we find a pro-cyclical pattern of pollution abatement expenditures, while in eight sectors those investments move counter-cyclical.

This paper is organised as follows. Section 2 outlines the theoretical model. Section 3 analyses the empirical evidence and section 4 concludes.

2 THEORY

In this section we will develop a formal timing model of a dynamic stochastic world where preferences for consumption and pollution today can differ from those for tomorrow. We will show that, under an optimal cleaning policy, the amount of current output that will be sacrificed for a cleaner future environment depends upon current and expected future values of utility of consumption, disutility of pollution, and the ratio of output from clean to dirty plants. Finally, we will show that demand and technology shocks that are perceived to be long-lasting have a different impact on current and future pollution than transitory shocks.

2.1 *The Model*

Consider an economy with two production technologies, a clean-production technology and a dirty-production technology.[1] At the beginning of period t, S_t infinitely lived consumer-workers are matched to clean-production sites, each producing Y_S units of a composite consumption good.[2] For simplicity, we distribute all workers over the unit interval. So, there are 1-S_t workers matched to dirty-production sites, who produce Y_D units of the composite consumption good. We assume that clean plants produce more output with the same amount of resources than dirty plants. So, $Y_S > Y_D$. Note that the problem does not become trivial in the sense that all workers will be matched to the clean-production sites ($S_t = 1$), because such a transfer will not be without costs, due to investment costs and the fact that clean plants do not remain clean forever in our model.

Let σ_t be the fraction of clean-producing sites that revert to dirty-producing sites at the beginning of period t. σ_t can be interpreted in a number of ways. First, it can be viewed as depreciation, capturing the idea that a constantly growing economy needs to continuously clean up the production process in order to keep the same absolute level of pollution. However, σ_t can also be interpreted as a variable that reflects changes in knowledge or awareness of the impact of certain production techniques on the environment. We will return to this issue later. Let Θ_t be the fraction of workers who move from dirty to clean-production sites in period t. Then the law of motion for state variable S_t is given by:

$$S_{t+1} = (1 - \sigma_t) S_t + \Theta_t (1 - S_t + \sigma_t S_t) \ . \tag{1}$$

1 This model draws on Davis and Haltiwanger's (1990) 'prototype' model of job reallocation.

2 There is only one (variable) input factor S_t which represents efficiency units of combinations of labour and capital input. This input factor will be called 'workers.'

Equation (1) gives the number of workers in the clean-production sector in period $t+1$ given the number of workers in this sector in period t. The first term at the right-hand side gives the number of clean plants which remain clean and the second term gives the fraction of old dirties plus new dirties which become clean-production sites in the next period. Finally, we will assume that there are operation costs involved when a dirty-production site is transformed into a clean-production site. These costs are equal to one unit of time input by one (dirt-producing) worker and can be interpreted as pollution abatement investment. So, during period t, $(1-\sigma_t)S_t$ workers are productive at a clean-production site, $(1-\Theta_t)(1-S_t+\sigma_t S_t)$ workers are productive at a dirty-production site and $\Theta_t(1-S_t+\sigma_t S_t)$ workers are transforming dirty plants into clean ones. Instead of the traditional trade-off between current consumption and future consumption, the problem here is, how much current consumption is going to be sacrificed for a cleaner current and future environment. The cleaning activities which go at the cost of current consumption can be viewed as savings.

We assume for simplicity's sake that clean plants do not pollute. Let the pollution in period t, P_t, be proportional to output produced at dirty-production sites in period t. The pollution index P_t can now be written as:

$$P_t = \mu(1-\Theta_t)(1-S_t+\sigma_t S_t)Y_D\,, \tag{2}$$

where μ stands for the emission-output ratio.

Now, let the utility function of all consumer-workers in period t depend on consumption and pollution, and be given by: $U(A_tC_t,B_tP_t)$. Where

$$U_C > 0,\, U_{CC} < 0,\, U_P < 0,\, U_{PP} < 0,\, U_{CP} = U_{PC} = 0\,.$$

Subscripts denote derivatives. A_t and B_t are utility shifters. A change in A_t will be interpreted here as an aggregate demand shock. B_t is a taste for the environment shifter. Furthermore, A_t, B_t and σ_t are assumed to follow first-order Markov processes. We will assume the following functional form for utility:

$$U(A_tC_t,B_tP_t) = A_t\hat{U}(C_t) - B_tf(P_t)\,. \tag{3}$$

Note that the above concavity assumptions with respect to the utility function imply:

$$\hat{U}_C(C_t) > 0,\, \hat{U}_{CC}(C_t) < 0,\, f_P(P_t) > 0,\, f_{PP}(P_t) > 0\,.$$

Finally, it is assumed that consumers' aggregate consumption in period t is equal to the aggregate production of the composite consumption good:

$$C_t = (1-\sigma_t)S_tY_S + (1-S_t+\sigma_tS_t)\,(1-\Theta_t)Y_D\,. \tag{4}$$

The (opportunity) costs of pollution abatement investments are in the form of foregone production and are represented by the term:

$$\Theta_t(1 - S_t + \sigma_t S_t)\,Y_D\,. \tag{5}$$

Now, for a given σ_t, a decision has to be made about the fraction of workers at dirty-production sites that will be allocated to cleaning activities. To keep things tractable, we will assume that it is always possible to transform dirty into clean-production sites. We can interpret σ_t now not only as the rate at which existing clean plants revert to dirty ones, but also as the rate at which clean-production techniques become available.

At time t, a worker chooses a contingency plan that maximises expected discounted (life time) utility, i.e. he chooses a sequence of functions maximising expected discounted (life time) utility, where the expectation is over the realisations of the shocks. So the decisions to be carried out in period $t = 1,2,\ldots$ will depend upon the information available at that time. Due to the existence of external effects the competitive equilibrium outcome will not be equivalent to the central planner's outcome, as the externalities will not be internalised without additional government policy. The decentralised competitive equilibrium outcome could, however, be made compatible with the central planner's outcome by forcing the market to internalise the externalities, e.g. by levying a (Pigovian) tax or by setting emission standards. In order to be able to characterise the reallocation process in response to demand and allocation shocks, we concentrate on the first-best solution to the problem (i.e. where the externalities are fully internalised), which is equivalent to the social planner's solution.

2.2 *The Social Planner's Problem*

The social planner's problem can be formulated as a stochastic dynamic programming problem. With $V(S,A,B,\sigma)$ denoting the planner's value function under the optimal policy, Bellman's functional equation can be written as:

$$\begin{aligned} V(S,A,B,\sigma) = max_{\Theta\in[0,1]}\,&[A\hat{U}[(1-\sigma)SY_S + (1 - S + \sigma S)\,(1-\Theta)\,Y_D] \\ &- Bf(P) + \beta E[V(\bar{S},\bar{A},\bar{B},\bar{\sigma})\,|\,A,B,\sigma]] \\ &s.t.\ \bar{S} = (1-\sigma)S + \Theta(1 - S + \sigma S)\,, \end{aligned} \tag{6}$$

where overlined variables denote next period values and where β is a discount factor.

For now, we are only interested in how the optimal policy function $\Theta(S,A,B,\sigma)$ reacts to innovations in A, B and σ. We will need the following proposition:

Proposition:
(i) A value function $V(S,A,B,\sigma)$ exists uniquely and is strictly concave in S.
(ii) There exists a unique optimal policy function $\Theta(S,A,B,\sigma)$.
(iii) At an interior solution, V is continuously differentiable in S.

Proof: Note that the utility function defined in equation (3) is strictly concave in its arguments. Using the assumption that $Y_S > Y_D$ it can easily be seen that the current value function (i.e. current period utility as a function of $(S,\bar{S},A,B,\sigma)$) is strictly joint concave in $(S,\bar{S})$.[3] The hypotheses of theorems 9.6-9.8 and 9.10 in Stokey et al. (1989) all hold.

We also refer the reader to Davis and Haltiwanger (1990, p. 149) who formulated a stochastic dynamic programming problem with the same properties.

The existence of a unique value function implies that we can treat the right-hand side of (6) as a standard maximisation problem. It should be noted that, from the law of motion for S (equation (1)), choosing Θ is equivalent to choosing $\bar{S}$. The first-order condition of the maximisation problem now implies that the optimal cleaning policy satisfies:

$$\begin{aligned} &A\hat{U}_C[(1-\sigma)SY_S + (1-\bar{S})Y_D]Y_D - Bf_P[\mu(1-\bar{S})Y_D]\mu Y_D \\ &\quad = \beta E\left[\frac{\partial V(\bar{S},\bar{A},\bar{B},\bar{\sigma})}{\partial \bar{S}} \,\middle|\, A,B,\sigma\right]. \end{aligned} \tag{7}$$

Equation (7) tells us that, under an optimal cleaning policy, the utility costs of foregone output minus the utility gains from less pollution are equal to the expected utility gains resulting from an improved future environment (because there are more clean-production sites), at the beginning of the next period.

It will be interesting to see how the number of workers allocated to cleaning activities responds to a fall in the number of currently open clean sites. One could, for example, think in this respect of the effect on optimal environmental policies, resulting from the increasing evidence of the existence of a global greenhouse effect. The moment we become aware of the fact that a global greenhouse effect exists, the fraction of clean-producing plants falls immediately. In order to assess the effects of such a fall, let us define *M*, the number of workers whose occupation changes from production of the composite consumption good to cleaning activities:

$$M_t = \Theta_t(1 - S_t + \sigma S_t)\,, \tag{8}$$

3 In fact, for strict joint concavity it suffices to assume that $Y_S > (1-\Theta)Y_D$.

thus:

$$\frac{\partial M}{\partial S} = -(1-\sigma)\Theta \, .$$

Since $\frac{\partial \bar{S}}{\partial S} = (1-\sigma) - (1-\sigma)\Theta$, we can write

$$\frac{\partial M}{\partial S} = \frac{\partial \bar{S}}{\partial S} - (1-\sigma) \, . \tag{9}$$

The first part of the right-hand side of (9) is similar to the consumption smoothing effect. The response to a negative wealth shock is not to decrease consumption to the full extent of the reduction in wealth, but to postpone part of the reduction in wealth at the cost of decreasing future consumption. According to the first part of the right-hand side of (9), the fact that there are less clean plants now will lead to a reduction in the quality of the future environment as well. The reason for this is that the consumer workers are only willing to partly lower their current consumption to compensate for the fall in S by shifting into cleaning activities (since $\partial\bar{S}/\partial S > 0$, $\bar{S}$ will decrease when S decreases). The second term of the right hand side of (9) gives the direct effect of S on M. For a given Θ, a fall in S will increase the necessity to transform more dirty-production sites into clean ones. It can easily be seen that the second term dominates. So, when the number of currently open clean sites falls, due for example to increasing knowledge of the existence of a global greenhouse effect, production will shift towards cleaner production techniques, though not to the full extent of the shock.

To get a better understanding of the relationship between current consumption, current pollution, future consumption, and future pollution, we can use (6) in combination with (7) to get:[4]

$$\frac{A\hat{U}_C - \mu B f_P}{E(\bar{A}\hat{U}_C)} = \beta E\left[(1-\bar{\sigma})\left(\frac{Y_S}{Y_D}\right) \middle| A, B, \sigma \right] . \tag{10}$$

Equation (10) gives an expression for the stochastic marginal rate of transformation and tells us that more present consumption will be allocated to the future when:

(1) the expected rate at which clean plants become dirty $(\bar{\sigma})$ is low,
(2) the expected ratio of output in clean and dirty plants (Y_S/Y_D) is high,
(3) the disutility from current pollution $(\mu B f_P)$ is high.

4 For a derivation, see Appendix A.

2.3 *Demand and Technology Shocks*

Demand shocks

When A falls, the utility of consumption decreases, and it will be optimal to transfer more workers from consumption goods production to cleaning activities (the optimal Θ will increase) and hence more workers will be reallocated from dirty to clean plants. More clean plants are opened because the marginal utility costs of foregone production, given by the left-hand side of (7), are lower when aggregate demand, A, is lower. An increase in Θ will, according to (8), lead to an increase in the number of movers, M, by $(1 - S + \sigma S)$ times the change in Θ. Shocks that are perceived to be long lasting have a different impact. In that case the future values of A on the right-hand side of (7) will also change and (partly) offset the original decrease in opportunity costs.

Technology and allocation shocks

First, consider an unexpected increase in σ; this is similar to a decrease of the number of clean sites, S. If the innovation in σ is considered to be persistent, the marginal rate of transformation (from future to current consumption) will fall, see equation (10). As a result, less current consumption will be sacrificed for an improved future environment.

An alternative form of an allocative disturbance is an increase in the ratio Y_S/Y_D, for example due to a new energy saving technology. This will according to (10) lead to substitution from current consumption to reallocation activity resulting in higher future consumption and a cleaner environment.

3 EVIDENCE

In environmental economics, theory seems to be ahead of empirics. While the implications of environmental degradation, environmental policy and resource restrictions have been analysed in many economic frameworks (e.g. growth, trade, and public finance), litte attention has been paid to the estimation of the effects theory predicts. The main reason for this is of course not a lack of interest, but a lack of data. While there is growing attention for economic data on environmental policy and its effects, this has not yet materialised in internationally available and reliable data.

A more fundamental reason for the lack of empirical substantiation of environmental economic theory is perhaps that most theories have a normative rather than a positive character. They describe an optimal or sub-optimal world that is often quite different from reality. Theories are therefore hard to verify with empirical evidence. This does however not preclude the important role for empirics as a means to assess the degree to which environmental policymakers act optimally. In light of the present analysis, this would mean that empirical analysis can tell us something about the optimality of current environmental policies.

In this section we present the results of an attempt to test whether environmental investments are specifically concentrated in recessions. We do this by looking for a business-cycle effect in series of pollution abatement capital expenditures (PACE) for 10 industrial sectors of Germany,[5] the Netherlands, and the USA. The series contain yearly data and cover the period between 1971 and 1991.[6] A short description of the data and their sources can be found in Appendix B.

The exact specification of the tests needs some explanation. The effect of the business cycle on PACE might be obscured because abatement technology is partly embedded in newly acquired capital. For this so-called *integrated* abatement technology, the assumption made in the model that the adjustment cost of installing new abatement capital is lowest during recessions, will probably not hold. Since investments in this kind of abatement capital are – by definition – highly correlated with replacements and expansions of the productive capital stock, gross investment figures can serve as a tool to distinguish between integrated and end-of-line abatement investments. Ideally, the way to do this is by using gross investments as an explanatory variable. This, however, creates a problem of multicollinearity since gross investments are correlated with the (detrended) sectoral output, which serves as the business-cycle indicator in our regressions. The alternative is to fix the gross investment coefficient to unity and use the (log of the) ratio of PACE to total gross investment, rather than PACE itself, as the dependent variable.[7] As a consequence, the hypothesis we test is not whether total PACE (integrated plus end-of-line) is counter-cyclical, but whether it is *more* counter-cyclical (less pro-cyclical) than total investment.

There are several ways to go about the estimation of the business-cycle effect. The potentially most revealing way would be by estimating the relation between PACE and sectoral output using an error correction model. In that case one could estimate the hypothesised negative short-run relationship, while allowing for a (probably positive) long-term link.[8] The time series in our sample, however, are not long enough to allow such division in short and long-term effects. Cointegration tests, for instance, could not establish a long-term relation between PACE

5 Germany is the territory of former West-Germany.

6 The Dutch series range from 1971 to 1990, the German data from 1975 to 1991, and the American data from 1973 to 1991.

7 To check whether this is not too large a restriction, we ran regressions with PACE as a dependent variable, and gross investments next to detrended sectoral output as independent variables (despite the multicollinearity problem). Then, we checked the hypothesis that all gross investment coefficients were equal to unity. For none of the regressions this hypothesis was significantly rejected.

8 A long-term relationship could arise because a growing economy tends to raise its environmental standards.

TABLE 1 – ORDER OF INTEGRATION OF PACE-INVESTMENT RATIO AND DETRENDED SECTORAL OUTPUT

Sector	ISIC	Netherlands		Germany		USA	
		pace/inv	output	pace/inv	output	pace/inv	output
food and tobacco	31	1	0	1	0	1	0
textile and leather	32	0	0	1	0	1	0
wood and wood products	33	1	0	1	0	1	0
paper products	34	1	0	1	0	1	0
chemicals	35	0	0	1	0	1	0
mineral products	36	0	0	1	0	1	0
basic metal	37	1	0	1	0	1	0
metal products	381	1	0	1	0	1	0
industrial machinery	382	1	0	1	0	1	0
electrical goods	383	1	0	1	0	1	0

and sectoral output.[9] Instead of aiming at both the long and the short-run relation, we will therefore concentrate on the latter. In other words, we will focus on the effect of upswings and downswings of the economy *relative to a trend*, on the PACE/investment ratio.

The business-cycle indicator is the detrended, real sectoral output (in logs). We detrended the output series using a Hoderick-Prescott (HP) filter, with λ – the ‘shadow price’ of non-linearity – set to 100. The HP filter is a means by which a trend can be estimated that minimises residuals, subject to a linearity constraint.[10]

We tested for unit roots in the series. Table 1 summarises the results, reporting the order of integration of the series. All PACE-ratio series, except for one German and four Dutch sectors, are integrated of the order one. The detrended output series are all stationary. Given the non-stationarity of the PACE-ratio series, we used first differences of (the logarithm of) all variables in the regressions.

For each country we estimated a system of equations of the form:

$$d(\ln PACE_j) = \alpha_j + \beta_j d(\ln DO_j) + \varepsilon_j\,,$$

where DO is the detrended sectoral output and j is the sector index. Since it is likely that unobserved macroeconomic factors affect the abatement investment decision, we allow for correlation between contemporaneous disturbances across

9 After establishing that both the abatement investment variable and sectoral output are first-order integrated, we tested for cointegration between the two variables, using the Johansen test. For 25 out of 30 sectors, cointegrating equations could not be found.

10 See King and Rebelo (1993) for a description of the HP filter, as well as its pros and cons.

sectors. We do this by estimating the systems using the Seemingly Unrelated Regressions Model (SUR).

The resulting coefficients – which can be interpreted as the business-cycle elasticity of the PACE ratio – are presented in Table 2. It is shown that for 10 out of 30 sectors the business-cycle elasticity is significant at the 5 per cent level. For one additional sector it is significant at the 10 per cent level. Of these significant elasticities 8 have a negative sign, indicating a counter-cyclical pattern. The other 3 significant coefficients are positive.

TABLE 2 – ESTIMATES OF THE EFFECT OF THE BUSINESS CYCLE ON THE PACE-GROSS INVESTMENT RATIO, IN THE MANUFACTURING SECTORS OF THE NETHERLANDS, GERMANY, AND THE USA

Sector	ISIC	elasticity		
		Netherlands	Germany	USA
food and tobacco	31	4.66 (1.34)	− 4.03* (− 2.41)	− .0196 (− .0127)
textile and leather	32	− 6.11 (− .667)	− 9.95* (− 2.80)	− .259 (− .0973)
wood and wood products	33	24.9* (2.28)	1.58 (.633)	− .568 (− .396)
paper products	34	13.9 (.891)	− 8.72* (− 3.10)	− .381 (− .108)
chemicals	35	− 5.67* (− 2.91)	− 2.46 (− 1.37)	.337 (.245)
mineral products	36	7.41* (2.49)	− .531 (− .321)	− 4.47* (− 2.24)
basic metal	37	3.76 (.863)	2.19 (.882)	.575 (.709)
metal products	381	− 11.3 (− .686)	2.77 (.606)	− 2.74* (− 2.45)
industrial machinery	382	8.60 (.762)	− 1.81 (− 1.36)	2.23* (2.06)
electrical goods	383	− 15.9* (2.69)	5.06 (1.59)	− 2.00** (− 1.63)

NOTES: *t*-statistics in parentheses. A single asterisk indicates significance at the 5% level. A double asterisk denotes significance at the 10% level.

The negative coefficients are quite evenly distributed over the countries. Germany and the US have three sectors with negative coefficients, the Netherlands two. For Germany no evidence of pro-cyclical abatement investment was found. For two Dutch sectors (notably *wood and wood products* and *mineral products*) a positive elasticity was found, suggesting that end-of-line PACE in this sector is pro-cyclical. The same is true for the American sector *industrial machinery*.

It is hard to detect a pattern over the sectors with significant coefficients. The only sector with significant coefficients of equal sign, for more than one country, is *electrical goods*, where for both the Netherlands and the USA a significant elasticity was found. This could imply that the timing of abatement investment is dominantly influenced by national factors, such as the method of regulation (i.e. taxes, laws, and covenants) or the compliance time-schedule imposed by the regulator.[11]

For many sectors, the estimations did not yield significant results. Therefore the outcome of our model is not unambiguously supported. There can be many reasons for this. Besides technical reasons, like the disputable quality of the PACE series, an important reason is possibly that the predicted counter-cyclical nature of environmental investments is the result of a theoretical model where environmental policy is set by a 'social planner.' The insignificant results could therefore be explained by non-optimal timing of the deadlines in environmental programs. If firms have to comply with regulation within a period where no recession occurs, they are forced to invest in a non-optimal moment in time.

Similar considerations might explain the positive coefficients. Environmental policy seems to have a cycle of its own, booming in times of economic prosperity and withering during times of recession. If that is the case, our model would predict that forward-looking policymakers declare environmental policy in economic upturn, and enact this declaration once the economy slows down. When declaration and implementation of environmental regulation are simultaneously carried out in the boom, pro-cyclical abatement investment is likely to be found.

4 CONCLUSIONS

In this paper we showed that in a perfect market economy, where all external effects are internalised in the prices, and which faces both demand and technology shocks, the best time to undertake activities that improve the future environment at the cost of current output and consumption is during a recession. This is because the opportunity costs of doing so are lowest then. There are reasons not

11 There is one other possible explanation for the insignificant results that deserves attention. This has to do with the fact that we had to use sectoral rather than firm data. It may well be the case that at the firm level, PACE increases after a negative demand shock but that this does not carry over to sectoral level. Especially when firms are very heterogeneous and are mainly hit by idiosyncratic shocks this sort of bias will be severe (see also Caballero (1992) on this issue).

to carry over this result to the real world. First of all there is no price for a clean environment, so the government should impose restrictions on the production process, which is indeed already done in many countries. But even when a government is able to define an optimal level of pollution and announces it at the right time, there may still be many market imperfections like e.g. imperfect information and credit rationing which prevent firms from timing their pollution abatement investments optimally.

To get a better view of the relevance of those market imperfections we collected sectoral data on pollution abatement investments for a number of countries. We found that in more than 25 per cent of the sectors the pollution abatement investments-total investment ratio moves counter-cyclical, while in 10 per cent of the sectors this ratio moves pro-cyclical. This result suggests that there is a potential role for government intervention. This first inquiry into the cyclical behaviour of environmental investment raises as many questions as it answers. Future empirical research should therefore focus on a better way to differentiate in the data between integrated and end-of-line technology and address the question of how the sectoral and country differences can be explained. The latter topic would involve scrutinising environmental policy in different sectors and countries, assessing its time structure and the nature of the abatement technology it triggers.

APPENDIX A

DERIVATION OF THE STOCHASTIC MARGINAL RATE OF TRANSFORMATION

Off corners and under the optimal reallocation policy function, the value function, V, is differentiable in S with[12]:

$$\begin{aligned}\frac{\partial V(S,A,B,\sigma)}{\partial S} &= A(1-\sigma)\hat{U}_C[C](Y_S-(1-\Theta)Y_D)\\ &\quad + \mu B f_P[P](1-\sigma)(1-\Theta)Y_D\\ &\quad + \beta(1-\sigma)(1-\Theta)E\left[\frac{\partial V(\bar{S},\bar{A},\bar{B},\bar{\sigma})}{\partial \bar{S}}\,\middle|\, A,B,\sigma\right],\end{aligned}$$

where overlined variables denote next period values.

12 For more evidence, see Lucas and Stokey (1989), chapter 9.

Dividing the above equation by Y_D and substituting (7) into this equation yields:

$$A(1-\sigma)\,\hat{U}_C[C]\left(\frac{Y_S}{Y_D}-(1-\Theta)\right)+\mu B f_P[P]\,(1-\sigma)\,(1-\Theta)$$
$$+\,(1-\sigma)\,(1-\Theta)\,(A\hat{U}_C[C]-\mu B f_P[P])=\frac{\left(\dfrac{\partial V}{\partial S}\right)}{Y_D}\,.$$

So,

$$A(1-\sigma)\,\hat{U}_C[C]\,\frac{Y_S}{Y_D}=\frac{\left(\dfrac{\partial V}{\partial S}\right)}{Y_D}\,.$$

Hence,

$$\beta E\left[\frac{\left(\dfrac{\partial V}{\partial \overline{S}}\right)}{Y_D}\right]=\beta E\left[\overline{A}(1-\overline{\sigma})\,\hat{U}_C[C]\left(\frac{Y_S}{Y_D}\right)\right].$$

Now, substituting (7) back gives:

$$A\hat{U}_C[C]=\beta E\left[\overline{A}(1-\overline{\sigma})\,\hat{U}_C[\overline{C}]\left(\frac{Y_S}{Y_D}\right)\middle|\,A,B,\sigma\right]+\mu B f_P[P]\,,$$

which can be rewritten as:

$$\frac{A\hat{U}_C[C]-\mu B f_P[P]}{E\,(\overline{A}\hat{U}_C[\overline{C}])}=\beta E\left[(1-\overline{\sigma})\left(\frac{Y_S}{Y_D}\right)\middle|\,A,B,\sigma\right].$$

APPENDIX B

DATA AND SOURCES

The data on gross PACE are taken from national sources, since no deliberate, international survey of these data exists. Moreover, there are a mere handful of countries were PACE data of the private sector are collected in a consistent manner and over a longer period. The best data can be found for the Netherlands, Germany, and the USA. Since these data are the result of national surveys, they cannot easily be compared. The dust has not yet settled on the discussion about the definitions and methodology that should ideally be used for abatement investment surveys. Recently, EUROSTAT tried to synchronize the national bureaus of statistics in the EU by suggesting a common methodology by the name SERIEE, but it is unlikely that the German and Dutch survey will be altered to comply with these directions in the near future.

Apart from the disparities in definitions, cross-country comparison of the data is hindered by the different systems that are used for the sectoral breakdown. Each country employs a different categorisation. The German breakdown is based on the *Systematik der Wirtschaftzweige, Fassung für Umweltstatistiken* (SYUM), the Dutch CBS uses the *Standaard Bedrijfs Indeling* (SBI), the American Bureau of the Census based the sectoral breakdown on the *Standard Industrial Classification* (SIC). In order to facilitate cross-country comparison, we fitted the series in a common system of classification: the International Standard Industrial Classification (ISIC).[13]

The German series are from the Statistisches Bundesamt *Investionen für Umweltschutz im produzierende Gewerbe* and cover the period from 1975 till 1991, on a yearly base. The Dutch data are from the Centraal Bureau voor de Statistiek *Milieukosten van Bedrijven*. The survey started in 1979, but estimations of PACE are available from 1971 till 1990. The Bureau of the Census publication *Pollution Abatement Costs and Expenditures* is the source of the American PACE series. The data range from 1973 till 1991. For 1987 no data are available.

Output and investment data are from the *OECD Sectoral Database*. Investment is gross fixed capital formation, output is real gross sectoral production.

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